Litter ammonia generation: Moisture content and organic versus inorganic bedding materials[1]

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ABSTRACT Negative impacts on the environment, bird well-being, and farm worker health indicate the need for abatement strategies for poultry litter NH_3 generation. Type of bedding affects many parameters related to poultry production including NH_3 losses. In a randomized complete block design, 3 trials compared the cumulative NH_3 volatilization for laboratory-prepared litter (4 bedding types mixed with excreta) and commercial litter (sampled from a broiler house during the second flock on reused pine wood chips). Litters were assessed at the original moisture content and 2 higher moisture contents. Broiler excrement was mixed with pine wood shavings, rice hulls, sand, and vermiculite to create litter samples. Volumetrically uniform litter samples were placed in chambers receiving humidified air where the exhaust passed through H_3BO_3 solution, trapping litter-emitted NH_3. At the original moisture content, sand and vermiculite litters generated the most NH_3 (5.3 and 9.1 mg of N, respectively) whereas wood shavings, commercial, and rice hull litters emitted the least NH_3 (0.9–2.6 mg of N). For reducing NH_3 emissions, the results support recommendations for using wood shavings and rice hulls, already popular bedding choices in the United States and worldwide. In this research, the organic bedding materials generated the least NH_3 at the original moisture content when compared with the inorganic materials. For each bedding type, incremental increases in litter moisture content increased NH_3 volatilization. However, the effects of bedding material on NH_3 volatilization at the increased moisture levels were not clearly differentiated across the treatments. Vermiculite generated the most NH_3 (26.3 mg of N) at the highest moisture content. Vermiculite was a novel bedding choice that has a high water absorption capacity, but because of high NH_3 generation, it is not recommended for further study as broiler bedding material. Controlling unnecessary moisture inputs to broiler litter is a key to controlling NH_3 emissions.

Key words: ammonia, bedding, broiler, litter, moisture content

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INTRODUCTION

Broiler chickens grown for meat consumption are usually raised on a floor covered with a bedding material. The combination of bedding material and bird excreta is referred to as litter. Historically, bedding-related research has focused on the effects of type of bedding material on broiler performance under various management scenarios. More recent research has begun to investigate bedding effects on NH_3 generation from litter. The type of bedding material affects litter physical properties, structure, NH_3 adsorption, and release rates because of differences in water adsorption capacity, rate of moisture release, and ongoing biochemical processes (Kuczynski and Slobodzian-Ksenicz, 2002).

Locally available (typically organic) materials are the usual source for broiler bedding. A common bedding material in Poland is long rye straw (Kuczynski and Slobodzian-Ksenicz, 2002). Wheat and barley straw (byproducts of cereal cultivation) and pine wood shavings are frequently used in Spain, but rice hulls can be found in the Mediterranean area where rice crops are prevalent (Garcia et al., 2007). In the United States, pine wood particles and rice hulls are common bedding materials, with pine shavings and sawdust considered the most desirable and widely used litter materials (Malone and Gedamu, 1995). Other materials that have been investigated for litter bedding, and that

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performed similarly, include paper products, gypsum, hardwood bark, peanut hulls, kenaf, sand, rice hull ash, softwood chipping fines, wood chips, composted municipal garbage, and leaves (Bowers et al., 2003; Chamblee and Yeatman, 2003). A few studies focused on sand as a bedding material, indicating that it supported adequate performance criteria (Bilgili et al., 1999a,b; Bowers et al., 2003; Miles and Chamblee, 2003). However, a study in southeast Asia found that sand and paddy straw did not support production parameters when compared with sawdust and rice husks (Anisuzzaman and Chowdhury, 1996).

Novel approaches in the search for optimal bedding may include proprietary blends of several materials, use of a mixture of locally available materials, or addition of other industry byproducts to a conventional bedding material. Grimes et al. (2006) compared aGroChips (a proprietary mix of cotton lint waste, gypsum, and newspaper; Novovita Inc., Raleigh, NC) with pine shavings in pen trials. Although more cake formation was associated with aGroChips, no other differences were found in bird performance (Grimes et al., 2006). Pelleted newspaper, evaluated in the United States, was found to be suitable for broiler production when placed alone at half the volume of sawdust (Malone and Gedamu, 1995).

The objective of the present research was to quantify NH_3 generation (as cumulative total volatilized) from broiler excreta using 5 litter substrates at 3 moisture contents. We hope that this work will provide guidance to producers as they select litter bedding relative to NH_3 emission rates.

MATERIALS AND METHODS

Experimental Design

To ascertain the effects of selected inorganic and organic bedding materials and moisture content on NH_3 generation from broiler litter, a factorial arrangement of treatments was used in a randomized complete block design. Three trials compared laboratory-prepared litter (4 bedding types mixed with excreta) and commercial litter (sampled from a broiler house) with a range of 3 moisture contents. This resulted in a balanced factorial design of 15 treatments. Two replicates of each bedding and moisture level combination were tested during each trial. Statistical models describing NH_3 loss were developed for each material.

Ammonia Measurement System

The method for measuring NH_3 volatilization from litter was described previously (Miles et al., 2008a) and was designated a chamber acid trap (**CAT**) system. In the CAT system, humidified air passes through 1-L containers holding individual litter samples. The system has 4 air supply manifolds, each having 12 restricted flow outlets. Each manifold outlet (48 total) provides precisely controlled air flow to the individual containers. Ammonia volatilized from the litter is trapped in a series of 2 flasks containing H_3BO_3 solution. The NH_3 measurement or response (mg of N) is determined colorimetrically by titrating the H_3BO_3 solution with HCl. The duration of each trial was 4 d. Air was supplied to the containers at an overall flow rate of 109 mL/min (SD of 12 mL/min) and H_3BO_3 trap contents were titrated at 24-h intervals.

Limited availability of excreta to mix with the bedding materials dictated a small sample size. To achieve a consistent size, litter samples (36.6 mL) were placed into plastic cups. For the convenience of placing and removing the samples to avoid possible spillage, the cups were situated on polyvinyl chloride cylinders (7 cm height × 5.1 cm inside diameter) housed in the 1-L containers of the CAT system. The cups provided a uniform volume and surface area (18.9 cm^2) for NH_3 volatilization from each sample. The experimental temperature was subject to the laboratory climate, which was recorded as 20.2°C (SD of 0.5°C) using a temperature data logger (HOBO H8 Pro Series, model H08–032–08, Onset, Pocasset, MA).

Litter Preparation

Excreta. Droppings were collected over an 8-d period from broiler chicks (initially 3 d of age) receiving a standard chick starter diet. The chicks were housed in batteries at the Mississippi State University poultry science department as part of another experiment. A drywall spatula was used to lift excreta from the stainless steel pans beneath the cages. Care was used to avoid feed spillage areas near the front and back edges of the cage. Excreta were collected at 3, 6, and 11 d of age for trials 1, 2, and 3, respectively. Each collection was placed in Ziploc bags (SC Johnson, Racine, WI) and stored unsealed in a refrigerator. Storage time for each before each trial was approximately 5 d. Just before mixture preparation, the excreta were placed in a bucket and homogenized using a paddle mixer.

Commercial Litter Sampling. Broiler litter was collected during the second flock on a commercial farm in Mississippi where the original bedding material was pine wood chips. Litter sampling was conducted approximately 3 d before each trial began to accommodate pretest treatment addition. Table 1 shows the initial litter characteristics (% moisture, pH). The bulk litter sample was collected at a depth of no more than 7.6 cm from a 61 cm × 91 cm area in the center non-brood end of the house. After transport to the laboratory, the gross sample was thoroughly mixed before taking subsamples for physical and chemical analyses. The bulk sample was loosely covered and refrigerated (3 d) until laboratory sample preparation.

Laboratory Sample Preparation. Litter samples were created by mixing the excreta with 4 separate bedding materials: 2 organic materials, wood shavings and rice hulls (each aged 6 mo), and 2 inorganic materi-

Table 1. Characteristics of excreta, bedding materials, and commercial broiler litter

Item	Moisture (%)	pH	Density (kg/m^3)	Absorbance (g of H_2O/g of DM)
Excreta	55.1	5.79	—[1]	—
Bedding material				
Wood shavings	7.1	5.01	170	1.88
Rice hulls	10.0	5.98	120	1.82
Sand	0.1	5.64	1,500	0.13
Vermiculite	1.0	6.14	125	4.23
Commercial litter				
Block 2	13.9	8.44	—	—
Block 3	26.7	7.43	—	—

[1]Dash indicates not measured.

als, vermiculite and medium silica (masonry) sand, at a 1:7 feces:bedding ratio (vol/vol). Commercial broiler farmers in the southeastern United States supplied approximately 19 L of both the wood shavings and rice hulls, originating from Mississippi and Kentucky, respectively. These materials were being stored on the respective farms in preparation for cleaning out houses and placing new bedding. The vermiculite used in the study was a horticultural product (Sta-Green, United Industries Corp., St. Louis, MO) formed by heat treating the naturally occurring mineral vermiculite (Vermiculite Association, 2010). The masonry sand was obtained from a local building supplier.

Moisture contents, pH, and bulk density of bedding materials are shown in Table 1. Because the excreta and commercial litter samples were discarded (because of loss of a freezer) before density measurements were performed, only moisture content and pH are given in Table 1 for these materials. At the end of the flock, density was estimated at 375 kg/m^3 (SD 9 kg/m^3) for the commercial litter. For all materials, moisture contents were measured by oven drying (48 h at 65°C). The pH was determined using a 5:1 mixture of deionized (**DI**) H_2O and the material. Bulk density was calculated based on the mass of a known volume of the material. Specifically, each bedding material was weighed in triplicate for volumes of both 40 and 80 mL. The SD was less than 6.5% among all measurements. Bedding material absorbance, given in Table 1, was measured using the method of Misselbrook and Powell (2005).

Predicting Water Application Rates to Attain Moistures. Preliminary mixtures of excreta and wood shavings in various ratios were examined to determine the ratio that would be used in the trials. The objective of these tests was to find moisture contents that were similar in magnitude to those that occur in commercial boiler houses. The tested ratios of excreta:wood shavings were 1:1 (50% excreta) to 1:7 (12.5% excreta). Figure 1 illustrates that decreasing the amount of excreta decreased the moisture content of the mixture. The 1:7 excreta:wood shavings mix gave a moisture content of approximately 30%. This ratio was chosen for the trials because of its similarity to commercial litter moisture content. Reported broiler litter moisture contents include 19 to 31% (Chamblee and Todd, 2002), 30 to 33.5% (Glancey and Hoffman, 1996), 22.7 to 25.5% (Miles et al., 2006), 22.6 to 36.4% (Miles et al., 2008b), and 25.6 to 29.7% (Sistani et al., 2003), indicating that a moisture content of approximately 30% for the excreta:wood mix was near the high end of a typical range.

Once the ratio of excreta to bedding material was established, samples for each treatment were prepared volumetrically (15 mL of excreta was mixed with 104 mL of bedding material). Samples were placed in Ziploc bags and refrigerated overnight before the beginning of each test. The mixing procedure was repeated 6 times for each material to produce 2 original moisture level mixtures and 4 allotments to receive moisture addition. Six bags of commercial litter containing 119-mL samples were also allotted and refrigerated.

The target moisture contents for the wood shavings prepared litter were 30 (the moisture content of the 1:7 mixture), 35, and 40%. Moisture intervals of 5% were chosen based on preliminary work indicating that these intervals could be produced with reasonable accuracy. The calculated mass of DI H_2O required to increase moisture content from 30 to 35% was 3.02 g (**1×H_2O**). The calculated mass required to increase moisture content to 40% was 6.36 g (**2×H_2O**). To prepare the moisture treatments of the other materials that were tested, an equivalent mass of DI H_2O was added to each. All water addition was accomplished by misting

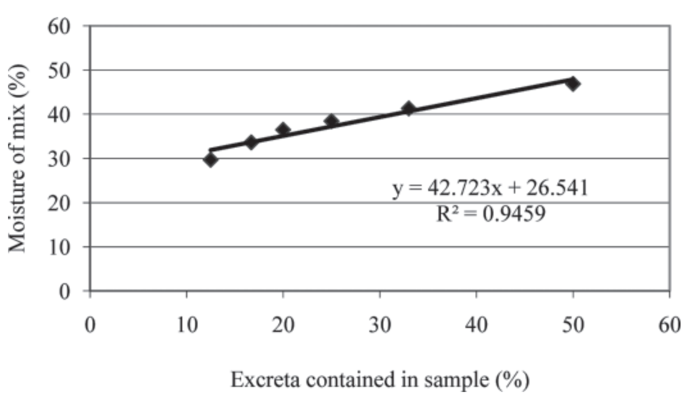

Figure 1. Moisture content of excreta:wood shavings mixture to determine initial volume:volume ratio.

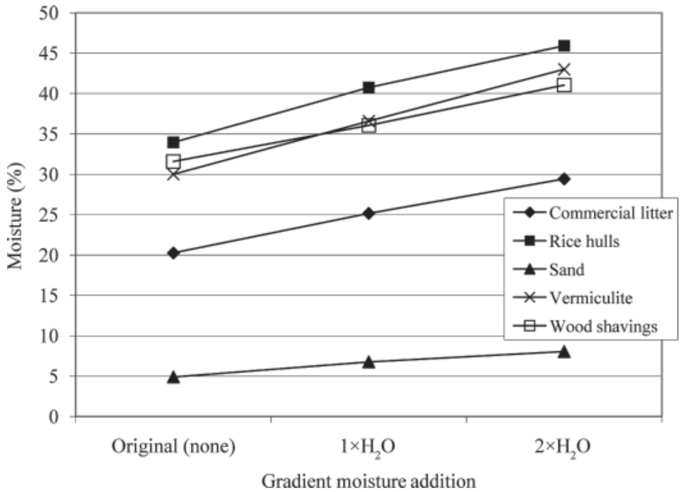

Figure 2. Initial moisture content of each bedding mixture for the original (no water addition or as mixed), level 1 addition ($1\times H_2O$ = 3.02 g), and level 2 addition ($2\times H_2O$ = 6.36 g).

the required mass of DI H_2O ($1\times H_2O$ or $2\times H_2O$) onto the samples contained in plastic bags.

Differences in the bulk density of the bedding materials were such that the $1\times H_2O$ and $2\times H_2O$ treatments did not result in 5% increases in moisture contents of the other materials. The initial moisture contents for each treatment (measured values averaged for blocks 2 and 3) are shown in Figure 2. The approximate interval increase with each moisture addition was as follows: wood shavings, 4.73%; commercial litter, 4.58%; rice hulls, 5.98%; vermiculite, 6.50%; and sand, 1.58%. The initial moisture contents for each excreta–bedding mixture were as follows: rice = 34%; wood shavings = 31.6%; vermiculite = 30%; commercial litter = 20.3%; and sand = 4.9%.

Statistical Analyses

Procedures of SAS (SAS Institute Inc., 2003) were used to analyze the NH_3 response to bedding and moisture effects. The distribution of the data was checked using PROC UNIVARIATE and was found to be positively skewed. The skewness was reduced to a satisfactory level (near 0) using a log (base 10) transformation, which was used in all analyses.

A repeated measures ANOVA was performed using PROC MIXED. The covariance structure was modeled using 5 candidate structures: unstructured covariance model, compound symmetry covariance, first-order autoregressive model, full Toeplitz model, and Toeplitz 2 level model. The minimal value for the Akaike information criteria (Akaike, 1974) was used to select the best covariance structure. A minimal Akaike information criteria (Littell et al., 2006) was produced with the unstructured covariance model, making it the appropriate structure for repeated measures analysis. Covariance analysis (PROC MIXED) was used to determine regression responses for the quantitative variables (gradient moisture and day of experimentation). The full statistical model predicting NH_3 release (mg of N) in response to moisture effects for each bedding type is

$$\log \text{predicted } NH_3 = b + \beta_{ML} \times M + \beta_{dL} \times d + \beta_{MdI} \times M * d + \beta_{dQ} \times d^2,$$

where b = the estimated intercept, M = moisture level classification (original = 0, $1\times H_2O$ = 1, $2\times H_2O$ = 2), d = day of experimentation (1, 2, 3, or 4), β_{ML} = estimated linear moisture coefficient, β_{dL} = estimated linear coefficient for day, β_{MdI} = estimated coefficient for the moisture–day interaction, and β_{dQ} = estimated coefficient for the quadratic day response. Differences among bedding and moisture treatments for the response of cumulative NH_3 volatilization were assessed with PROC MIXED. Means separation procedures (least significant difference–PROC GLIMMIX) were used to assess differences among treatments.

RESULTS AND DISCUSSION

For the above model for the daily NH_3 release of each material, Table 2 gives the significance level of each source of variation (moisture content level and day of experimentation). The moisture–day interaction was significant only at the $\alpha = 0.05$ level for the commercial broiler litter ($P = 0.0247$), which indicates that the behavior of the NH_3 release from built-up litter was different than that of the laboratory-created litter, which would be expected. The differences in the log model because of the interaction term are shown in Figure 3. Figure 3A gives the log model for the wood shavings as an example for all materials because the basic response is the same with differences only in magnitude. Figure 3B results from including the interaction term for the commercial litter. The difference in the behavior of the commercial and laboratory-created litters is expected and could be attributed to many growout features (e.g., bird, microbial, and facility factors). Future studies could benefit from comparing commercial litters originating from various substrates. Evaluating different litters subject to similar bird and house management factors may yield useful results relative to NH_3 generation and long-term bedding selection. That research effort is beyond the scope of the current study.

Back transforming the log models to the original scale shows the response of NH_3 volatilization from each excreta:bedding mixture and the commercial broiler litter (Figure 4A–E). For each material, the high level of moisture addition ($2\times H_2O$) produced the most NH_3 on d 2, 3, and 4, but response on d 1 was similar at all moisture levels. For each moisture level, the amount of NH_3 volatilized increased through d 3. Between d 3 and 4, NH_3 response flattened or decreased or increased only slightly for wood shavings, rice hulls, and sand. However, NH_3 continued to increase between d 3 and 4 for vermiculite and commercial litter. In other research,

Table 2. The ANOVA significance level for predicting NH_3 volatilization from selected bedding materials and commercial broiler litter in the chamber acid trap system

Source of variation	Wood shavings	Rice hulls	Sand	Vermiculite	Commercial litter
Moisture[1]	0.0002	<0.0001	<0.0001	<0.0001	0.0003
Day[2]	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Moisture × day	0.0925	0.2772	0.4042	0.4073	0.0247
Day × day	0.0010	0.0023	<0.0001	<0.0001	0.0104

[1]Litter moisture content at 3 levels: no H_2O added, 3.02 g of H_2O added, and 6.36 g of H_2O added.

[2]Day of experimentation (1–4) within chamber acid trap system.

differences in bedding performance as a function of time have been reported. Investigating effects of soft wood shavings and long and chopped rye straw for turkey rearing, Kuczynski and Slobodzian-Ksenicz (2002) saw no differences for total NH_3 generation but significant differences for NH_3 emitted based on time (wk) beyond bird placement as well as significant seasonal effects for long straw litter. Maximum emissions were found at wk 6 to 7 for long straw but at approximately wk 10 for wood shavings and chopped straw.

The trends in NH_3 generation provide valuable knowledge about emission potential relative to each bedding type. However, determining which material minimizes NH_3 production is very useful to the poultry industry. The cumulative NH_3 generated for each material was evaluated for this purpose (Figure 5). Assessing the cumulative NH_3 generated among the bedding and gradient moisture treatments indicated that materials and moisture levels were linked on multiple levels.

At the initial moisture level, vermiculite and sand produced significantly more NH_3 than litter, rice, and wood shavings (Figure 5). For 1×H_2O addition, vermiculite (19 mg of N) and sand (11.5 mg of N) were not significantly different and produced the greatest amount of NH_3, but sand was not significantly different than rice hulls (6.4 mg of N) and the commercial litter (5.1 mg of N), having a lower NH_3 yield. Minimal NH_3 generation at 1×H_2O was from rice hulls, commercial litter, and wood shavings (3.5 mg of N). At 2×H_2O, vermiculite (26.3 mg of N), sand (18.5 mg of N), wood shavings (15.3 mg of N), and rice hulls (12.1 mg of N) were not significantly different for NH_3 production. The commercial litter (7.1 mg of N) generated the least amount of NH_3 but was not statistically different from the rice hulls or wood shavings.

Based on these results, for the original moisture conditions, the better choices for litter bedding material would be wood shavings or rice hulls to minimize NH_3 emissions. These materials performed similarly to the commercial broiler litter for cumulative NH_3 generation. Increasing moisture by approximately 5 and 10% in the wood shavings (1×H_2O and 2×H_2O, respectively) resulted in significant increases in cumulative NH_3 generation for each incremental moisture increase. The same gravimetric moisture additions to commercial litter and the rice hull–excreta mix increased NH_3 generation from the original moisture level, but the 1×H_2O and 2×H_2O additions were not different. Although mean NH_3 yield increased with moisture increase for the sand and vermiculite, the only significant differences were between the original moisture and the 2×H_2O level. Thus, to some degree in each material, moisture addition increased NH_3. These findings should be confirmed among additional field studies. Future experimental designs could include extended testing timeframes for assessing NH_3 volatilization to ascertain whether the inorganic materials exhibit initial rapid release with volatilization then slowing because of N depletion or stabilization of microbial populations.

Other research supports limiting moisture to reduce NH_3 losses. Managing litter moisture for NH_3 reduc-

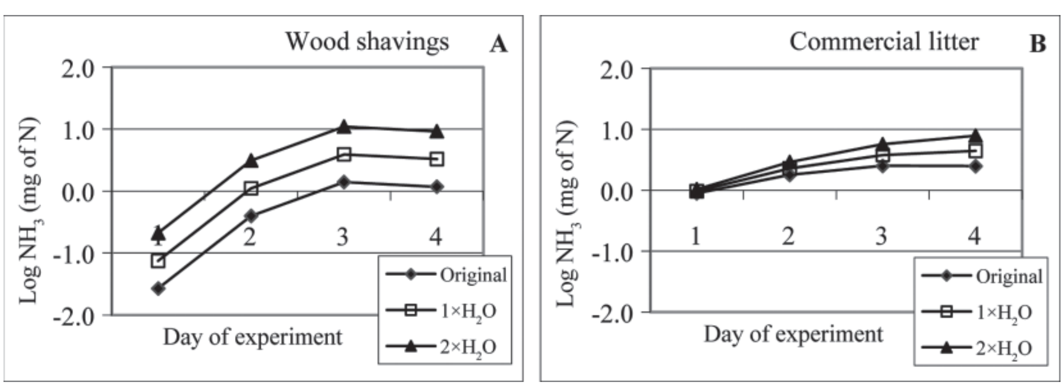

Figure 3. Log_{10} model predictions for volatilized NH_3 (mg of N) in laboratory-created litter and commercial broiler litter over time. A) Wood shavings example representative of rice, sand, and vermiculite. B) Model for commercial broiler litter. Original = no water added; 1×H_2O = 3.02 g of H_2O added; 2×H_2O = 6.36 g of H_2O added.

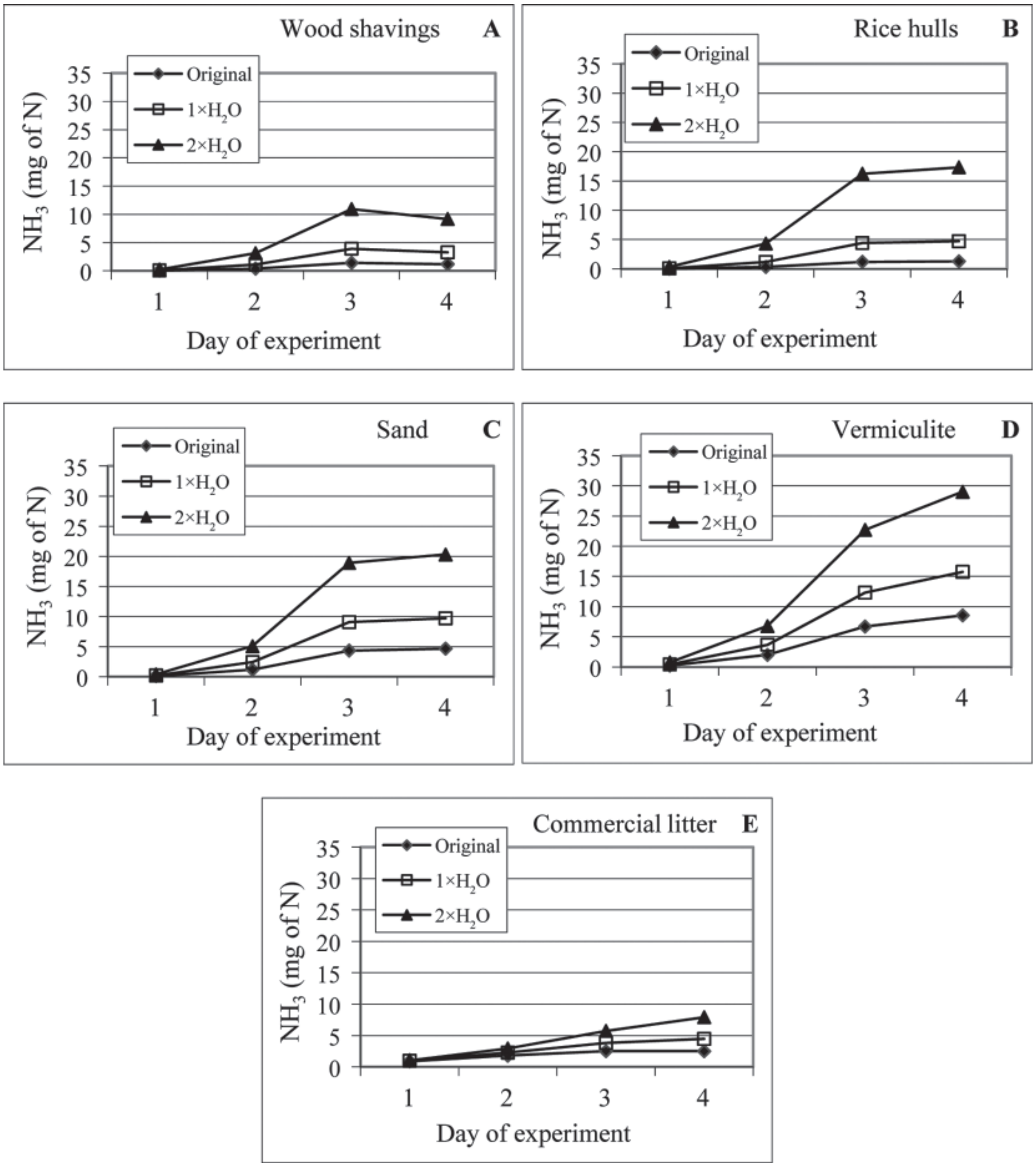

Figure 4. Daily model predictions for volatilized NH_3 (mg of N) for broiler excreta:bedding materials mixture and commercial broiler litter (values transformed from log notation). Original = no water added; $1\times H_2O$ = 3.02 g of H_2O added; $2\times H_2O$ = 6.36 g of H_2O added.

tion is important not only within broiler houses but in outside storage. Exposure to rainfall can significantly increase litter moisture content (Glancey and Hoffman, 1996). Studying the effects of potential NH_3 and CO_2 emission, H_2O content, and inorganic N for litter storage of whole and fine fractions, Cabrera et al. (1994) found significantly greater emission potential at 50% H_2O content compared with the unamended (lower) H_2O level. Garcia et al. (2007) reported higher NH_3 that corresponded with greater litter moisture content. Cabrera and Chiang (1994) reported that NH_3 volatilization occurred at unamended H_2O content from 2 commercial broiler litters and increased with greater water content. Their determination of water content and relative water-holding capacity lacked details to support a direct comparison with the moisture contents of the current study.

Andersson (1995) investigated various bedding materials and mixtures used to absorb NH_3 from pig manure. Andersson (1995) found different performances based on time after manure application (1 d, 1 wk, or 8 wk), and only pH showed a (slight) correlation with NH_3 emission. Barley straw and newspaper had about the same H_2O-absorbent capabilities and were 70 to 75% less absorbent than peat. Straw, straw–newspaper mix, and straw–peat mix resulted in the lowest NH_3 emissions at 8 wk, but were at the mid level of NH_3 production at 1 wk. In broiler research, Al Homidan et al. (1997) reported that increased NH_3 concentrations were associated with restricted amounts of wood shavings litter (3 vs. 4.5 cm depth), which seemed to relate to absorption capacity.

Researchers have attempted to characterize NH_3 losses with respect to a material's ability to absorb mois-

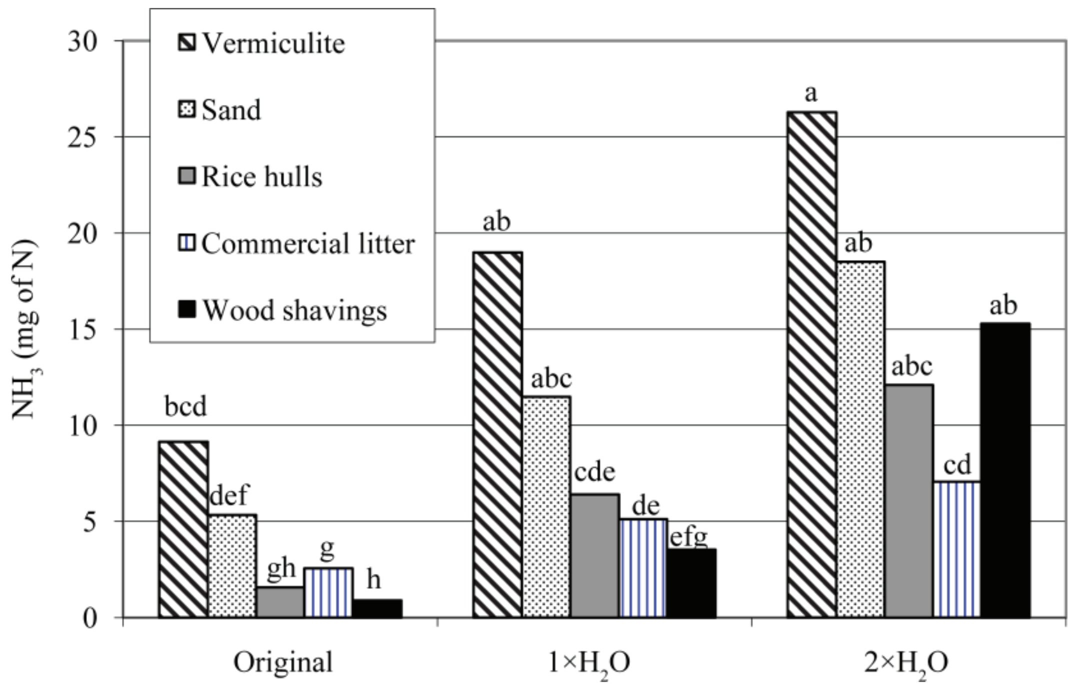

Figure 5. Cumulative NH_3 generation (mg of N) by excreta:bedding mixtures and commercial broiler litter. Original = no water added; 1×H_2O = 3.02 g of H_2O added; 2×H_2O = 6.36 g of H_2O added. Lack of common letters (a–h) above each bar indicates significantly different NH_3 emitted among the treatments (α = 0.05). Color version available in online PDF.

ture, but inferences for bedding performance relative to moisture absorption capacity are not well defined. Water-holding capacity of poultry litter (original bedding wood shavings) can be as high as 3 kg/kg (Cabrera et al., 1994), equivalent to 300% moisture content on a wet weight basis. In the current study, vermiculite had the highest capacity to absorb moisture and sand had the least capacity. Yet, the vermiculite and sand litters released the most NH_3 at the original moisture level. Based on the literature reports and the current study results, bedding absorption capacity is not a good indicator of potential to maintain or release NH_3.

In conclusion, NH_3 volatilization from laboratory-created litters and commercial litter was quantified for cumulative NH_3 loss in the acid trap system, and models predicting daily NH_3 release for each material were reported. The range of initial moisture for the commercial litter was 20 to 30%, with sand litter much lower at 5 to 8% and rice hull, wood shavings, and vermiculite litters having greater moisture (30–46%). Increasing litter moisture content increased NH_3 generation for all materials. At the 2 higher moisture levels, the responses were complex and the best bedding choice was not obvious.

At the initial moisture levels, wood shavings and rice hull litters emitted the least NH_3 and were comparable with the commercial litter. Sand and vermiculite litters generated more NH_3 at the initial moisture level. Thus, the organic bedding materials performed better than the inorganic types with respect to lower NH_3 generation. The results support recommendations for using wood shavings and rice hulls, already popular bedding choices in the United States and worldwide, for limiting litter-generated NH_3. Although sand has been deemed an acceptable bedding material for broiler performance, it is not recommended as a bedding material because of NH_3 emissions. Vermiculite was a novel bedding choice having a high water-absorption capacity, but the high NH_3 generation indicates it has little potential value as broiler bedding material.

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